SYSTEM FOR REMOVAL OF INERTS FROM FUEL CELL REACTANTS

RELATED APPLICATIONS

This application claims priority under 35 U.S.C. §119(e) from U.S. Provisional Patent Application No. 60/431,925, that was filed on December 9, 2002, that is entitled "INERT REMOVAL SYSTEM FOR PEM FUEL CELLS," and the entire disclosure of which is hereby incorporated by reference in its entirety herein.

FIELD OF THE INVENTION

The present invention generally relates to fuel cells and, more particularly, to a system for removal of inert gases from one or more fuel cell reactants.

BACKGROUND OF THE INVENTION

Fuel cells are devices that convert chemical reactants, namely an oxidant/oxidizer and a fuel, into electricity. Recent advances in fuel cell technology have increased their efficiency and lowered their cost, which has allowed fuel cells to compete with other more conventional types of energy conversion devices such as combustion engines and batteries. The variety in the types and sizes of fuel cells makes them versatile for use in a variety of applications, including providing electrical power for laptop computers, powering vehicles, and even providing electrical power for homes.

Fig. 1 illustrates a typical electrical power generator **100** that utilizes a fuel cell **102** to generate electricity. Electrical power generator **100** includes recycle system **112** for a fuel. Fuel cell **102** has a fuel inlet **104** for input of fuel into fuel cell **102** from a fuel

source. Any fuel not consumed by fuel cell **102** for the generation of electricity exits fuel cell **102** through fuel outlet **106**. Fuel recycle system **112** recirculates unconsumed fuel from fuel outlet **106** back to fuel inlet **104**.

Fuel cell **102** also has an oxidant inlet **108** for input of oxidant into fuel cell **102** from an oxidant source. The oxidant will chemically react within the fuel cell with the fuel to produce electricity and a reactant product. The reactant product generated by the reaction of the oxidant and the fuel will exit fuel cell **102** through oxidant outlet **110**. The reactant product may be discharged for disposal.

One type of fuel cell that has garnered a significant amount of research and interest is the polymer electrolyte membrane (PEM) fuel cell. The PEM fuel cell operates by supplying hydrogen to an anode, where a catalyst, typically a platinum-containing catalyst, separates the hydrogen into electrons and protons. The electrons that are separated from the hydrogen are transported to a cathode via an external circuit, which can be used to provide electrical power for a desired application/electrical load (electric motor, communication systems, propulsion systems, etc.). The protons are transported from the anode to the cathode through a solid electrolyte, namely a polymer electrolyte membrane (PEM). The PEM is a solid polymer and is typically made from a proton conductive fluoropolymer.

Oxygen is supplied to the cathode of the PEM fuel cell as pure oxygen or oxygen diluted with other gases. For example, the oxygen can be supplied to the cathode in the form of ambient air. At the cathode, the protons and electrons, aided by a catalyst, combine with the oxygen to produce water as a reactant product.

One problem encountered by some PEM fuel cells is a build up of inert gases (inerts) on the anode side of the fuel cell. The inerts diffuse into the fuel cell from the ambient environment because of the low partial pressure of nitrogen and other inerts present in the fuel cell system. Additionally, if the oxygen feed into the cathode contains inerts, for example if air is used, then the inerts in the oxygen feed will eventually diffuse from the cathode to the anode side of the fuel cell. The build up of inerts on the anode side of the fuel cell has the effect of displacing the hydrogen. The displacing of the hydrogen by the inerts keeps the hydrogen from contacting the catalyst and generating electrons and protons. When the inerts reach a high enough concentration, very little, if any, hydrogen contacts the catalyst and the fuel cell stops producing electricity.

Conventionally, the inerts problem is handled by periodic venting/purging of the anode side of the fuel cell. The venting/purging removes the inerts from the anode, thereby allowing the hydrogen access to the catalyst. However, when the anode side of the fuel cell is purged, valuable hydrogen is also purged. The amount of hydrogen purged with the inerts can be at least somewhat controlled to limit the amount of lost hydrogen by timing the purge cycle to efficiently remove the inerts. Even with efficient purging of the anode, however, a significant portion of the hydrogen is lost to purging of the inerts.

Depending on the application of the fuel cell, losing 10 percent of the hydrogen on every purge may be tolerable. For example, in automotive applications, losing 10 percent of the hydrogen on every purge is not a significant issue because the vehicles must be periodically re-fueled anyway. In closed loop systems such as space systems and

the like, efficiencies are of major importance and losing 10 percent of the hydrogen each purge is not acceptable.

Thus, there is a need for an improved way of dealing with inerts in hydrogen fuel cells, particularly closed looped systems, that reduces or eliminates the purging of valuable hydrogen.

BRIEF SUMMARY OF THE INVENTION

A first aspect of the present invention is embodied by an electrical power plant that generally includes a fuel cell and a first reactant recycle system. The fuel cell includes a first reactant inlet (e.g., an inlet for a first reactant) and a first outlet (e.g., for a first discharge out of the fuel cell). The first reactant recycle system is fluidly interconnectable with the first outlet of the fuel cell. "Fluidly interconnectable" herein means that the relevant components may be in constant fluid communication or may be selectively placed in fluid communication (e.g., by operation of a valve). In any case, the first reactant recycle system includes a separator. This separator in turn includes a separator inlet, a first separator outlet, and a second separator outlet. The separator inlet is fluidly interconnectable with the first outlet of the fuel cell, the first separator outlet is fluidly interconnectable with the first reactant inlet of the fuel cell, and the second separator outlet is fluidly interconnectable with the separator inlet without having to progress back through the fuel cell. The second separator outlet may be viewed as a fuel cell bypass for redirecting a flow back into the separator.

Various refinements exist of the features noted in relation to the first aspect of the present invention. Further features may also be incorporated in the first aspect of the

present invention as well. These refinements and additional features may exist individually or in any combination. The fuel cell may be of any appropriate configuration and may use any appropriate reactant or combination of multiple reactants. In one embodiment, the fuel cell is in the form of a polymer electrolyte membrane fuel cell. The first reactant inlet thereby may be associated with a single fuel cell or with a plurality of fuel cells, and may be of any appropriate configuration. Similarly, the first reactant recycle system may receive a discharge from a single fuel cell, from multiple fuel cells (e.g., a fuel cell stack) or multiple fuel cell stacks. The first outlet thereby may be associated with a single cell or with a plurality of fuel cells.

A flow or discharge from the first outlet of the fuel cell to the first reactant recycle system may be controlled in the case of the first aspect. For instance, a valve may be disposed in-line with a conduit extending between the first outlet of the fuel cell and the first reactant recycle system. Similarly, a flow or discharge from the separator of the first reactant recycle system, through the second separator outlet back to the separator inlet (that again bypasses the fuel cell), may be controlled as well. The flow or discharge from the separator through its second separator outlet may be selectively directed to one of multiple flowpaths. For instance, the flow or discharge from the separator through the second separator outlet may be directed through a conduit to a three-way valve. One of the outlet ports to this valve may direct a flow or discharge back to the separator inlet in a manner that bypasses the fuel cell. Another of the outlet ports to this valve may direct a flow or discharge to an appropriate source (e.g., a storage vessel; outside the electrical power plant; a second reactant inlet that may be associated with the fuel cell, and that will be discussed in more detail below).

The first separator inlet associated with the first aspect may be in any appropriate form, including without limitation in the form of a single port, in the form of individual multiple ports, or in the form of a common manifold associated with multiple inlet conduits to the separator. The second separator outlet may be fluidly interconnectable with the separator inlet in any appropriate manner. For instance, a conduit may extend from the second separator outlet to a conduit that extends from the first outlet of the fuel cell to the separator inlet. Another option would be for a conduit to extend from the second separator outlet directly to the separator inlet (e.g., one conduit could extend from the first outlet of the fuel cell to one port of the separator inlet, and another conduit could extend from the second separator outlet to another port of the separator inlet).

The first reactant inlet for the fuel cell used by the first aspect may be in any appropriate form, including without limitation in the form of a single port, in the form of individual multiple ports, or in the form of a common manifold associated with multiple first reactant inlet conduits to the fuel cell. The first separator outlet may be fluidly interconnectable with the first reactant inlet of the fuel cell in any appropriate manner. For instance, a conduit may extend from the first separator outlet to a conduit that extends from a first reactant storage vessel or source to the first reactant inlet of the fuel cell. Another option would be for a conduit to extend from the first separator outlet directly to the first reactant inlet of the fuel cell (e.g., one conduit could extend from the first separator outlet into one port of the first reactant inlet, and another conduit could extend from a first reactant storage vessel or source to another port of the separator inlet). Yet another option would be for a conduit to extend from the first separator outlet to a first

reactant storage vessel or source that is fluidly interconnectable with the first reactant inlet of the fuel cell.

The separator used by the electrical power plant of the first aspect may be of any appropriate configuration. In one embodiment, this separator includes an anode and a cathode that are separated by a solid electrolyte. Any appropriate solid electrolyte may be utilized, including without limitation a polymer, a fluoropolymer, a ceramic, or a metal oxide. Typically the solid electrolyte will be tailored to the type of the first reactant that is to be recovered from the flow out of the first outlet of the fuel cell for re-direction to the first reactant inlet.

The electrical power plant of the first aspect may be characterized as including a first flowpath (e.g., created by a conduit) from the first outlet of the fuel cell to the separator inlet, a second flowpath (e.g., created by a conduit) from the first separator outlet to the first reactant inlet of the fuel cell, and a third flowpath (e.g., created by a conduit) from the second separator outlet back to the separator inlet that bypasses the fuel cell. The first reactant recycle system may include an accumulator that is associated with the first flowpath such that the accumulator is disposed between the first outlet of the fuel cell and the separator. The third flowpath (associated with the second separator outlet) may merge with the first flowpath (associated with the separator inlet) at a location that is between the accumulator and the separator, or at a location between the accumulator and the first outlet of the fuel cell. Another option would be for the first and third flowpaths each to individually connect with the separator inlet. In any case, an appropriate valve or the like may be associated with the third flowpath to control the flow from the second separator outlet back to the separator inlet in a manner that bypasses the fuel cell. An

appropriate pump or other fluid displacement device also may be associated with the third flowpath to provide a flow from the second separator outlet back to the separator inlet in a manner that bypasses the fuel cell.

The fuel cell utilized by the first aspect may include a second reactant inlet and a second outlet. A first reactant source (e.g., a fuel, such as hydrogen) may be fluidly interconnectable with the first reactant inlet, while a second reactant source (e.g., an oxidant/oxidizer, such as air, pure oxygen, or a combination thereof) may be fluidly interconnectable with the second reactant inlet. A second reactant recycle system may be associated with the second outlet of the fuel cell for recovering a second reactant for re-use in the fuel cell. In one embodiment, this second reactant recycle system uses an anode and a cathode that are separated by a solid electrolyte. Another embodiment utilizes multiple recovery chambers or vessels for the second reactant recycle system.

A second aspect of the present invention is embodied by an electrical power plant that includes a fuel cell, a first reactant recycle system, a first flowpath, a second flowpath, and a third flowpath. The fuel cell includes a first reactant inlet and a first outlet. The first reactant recycle system includes a separator that in turn includes a separator inlet, a first separator outlet, and a second separator outlet. The first flowpath extends from the first outlet of the fuel cell to the separator inlet. The second flowpath extends from the first separator outlet to the first reactant inlet of the fuel cell. The third flowpath extends from the second separator outlet to the separator inlet, bypassing the fuel cell.

Various refinements exist of the features noted in relation to the second aspect of the present invention. Further features may also be incorporated in the second aspect of

the present invention as well. These refinements and additional features may exist individually or in any combination. The various features discussed above in relation to the first aspect may be used by this second aspect, individually or in any appropriate combination.

A third aspect of the present invention is embodiment by a method for generating electrical power. A first reactant feed is provided to a fuel cell for the production of electrical power. A first exit stream from the fuel cell is directed to a separator. At least a portion of the first reactant in the first exit stream is separated from the remainder to define a first separated reactant stream. This first separated reactant stream is directed out of the separator. A portion of the first exit stream from the fuel cell is recycled/recirculated through the separator without having to pass back through the fuel cell to continually allow the first reactant to be recovered from the first exit stream.

Various refinements exist of the features noted in relation to the third aspect of the present invention. Further features may also be incorporated in the third aspect of the present invention as well. These refinements and additional features may exist individually or in any combination. The first reactant feed may be a fuel (e.g., hydrogen) or an oxidant/oxidizer (e.g., oxygen, and including pure oxygen, air, or a combination thereof). In the case where the first reactant is in the form of hydrogen, the separator may utilize an anode, a cathode, and an intermediate solid electrolyte that transports hydrogen ions from the anode to the cathode. In the case where the first reactant is in the form of oxygen, the separator may utilize an anode, a cathode, and an intermediate solid electrolyte that transports oxygen ions from the cathode to the anode.

Both inerts and first reactant will typically be contained in the first exit stream from the fuel cell in the case of the third aspect. Preferably a substantial portion of the first reactant is recovered from this first exit stream out of the fuel cell, at least ultimately for reuse by the fuel cell for generating electrical power. The first separated reactant stream containing the recovered first reactant may be directed to an appropriate first reactant storage vessel or source that is fluidly interconnectable with the fuel cell, or may be directed immediately back to the fuel cell for use in the generation of electrical power. Remaining portions of the first exit stream are re-processed to enhance the amount of first reactant that is recovered. Preferably, substantially little to no first reactant remains in the first exit stream after processing in accordance with the third aspect has been terminated.

Recycling of the first exit stream from the fuel cell through the separator in accordance with the third aspect may be initiated after terminating the discharge of the first exit stream from the fuel cell. That is, "first exit stream" encompasses a volume of fluid that has been discharged from the fuel cell, and is not limited to a continual flow from the fuel cell. This volume of fluid is processed to preferably maximize the recovery of first reactant therefrom. Once the desired amount of recovery of first reactant has been realized, the remaining, now preferably first reactant depleted fluid may be directed out of the separator. One option would be to discharge the first reactant depleted fluid to the environment. Another option would be to discharge the first reactant depleted fluid to an appropriate storage vessel. Yet another option would be to discharge the first reactant depleted fluid into a second reactant inlet that may be associated with the fuel cell.

The fuel cell used in relation to the third aspect may direct a second reactant (e.g., oxidizer) into the fuel cell for use in the generation of electrical power. A second exit stream containing second reactant may be directed out of the fuel cell. At least part of the second reactant in this second exit stream may be recovered by using an appropriate solid electrolyte membrane disposed between an anode and cathode. Another option for recovering at least part of the second reactant from the second exit stream would be to use at least two different recovery chambers/vessels. Yet another option is for the second reactant to be recovered using at least two different recovery chambers/vessels and by using an appropriate solid electrolyte membrane disposed between an anode and cathode.

A fourth aspect of the present invention is embodied by an electrical power plant that includes a fuel cell, a first reactant recycle system, and a second reactant recycle system. The fuel cell includes a first and second reactant inlets, as well as first and second outlets. The first reactant recycle system is fluidly interconnectable with the first outlet of the fuel cell, while the second reactant recycle system is fluidly interconnectable with the second outlet of the fuel cell. The first reactant recycle system includes a separator in the form of a cathode and an anode separated by a solid first electrolyte, and functions to recover a first reactant for reuse by the electrical power plant. The second reactant recycle system may be in one of two forms, but in any case functions to recover a second reactant for reuse by the electrical power plant. One option is for the second reactant recycle system to be in the form of a cathode and an anode separated by a solid second electrolyte. Another option is for the second reactant recycle system to utilize multiple recovery chambers or vessels. Yet another option is for the second reactant

recycle system to utilize at least two different recovery chambers/vessels and utilize an appropriate solid electrolyte membrane disposed between an anode and cathode.

Various refinements exist of the features noted in relation to the fourth aspect of the present invention. Further features may also be incorporated in the fourth aspect of the present invention as well. These refinements and additional features may exist individually or in any combination. The various features discussed above in relation to the first aspect may be used by this fourth aspect, individually or in any appropriate combination.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows a schematic of a conventional (prior art) electrical power generator utilizing a fuel cell and including a reactant recycle system for the fuel.

Figures 2a and 2b show schematics of electrical power generators using two different embodiments of reactant recycle systems.

Figures 3 and 4 show illustrations of two different separators that may be used by the reactant recycle systems of Figures 2a and 2b, respectively.

Figure 5 shows a schematic of another embodiment of an electrical power generator that includes a reactant product recovery system.

Figure 6 shows a flow diagram of one embodiment of a regenerative fuel cell system.

Figure 7 shows a more detailed schematic of a regenerative fuel cell system in accordance with the embodiment of Figure 6.

DETAILED DESCRIPTION OF THE INVENTION

The present invention will now be described in relation to the accompanying drawings, which at least assist in illustrating its various pertinent features.

Fig. 2a shows a schematic of one embodiment of an electrical power generator and that is identified by reference numeral **200a**. Electrical power generator **200a** includes a fuel cell **202a** that operates to produce electrical power by reacting hydrogen and oxygen. The term "fuel cell" is intended to include a singe fuel cell and/or a plurality of fuel cells in a fuel cell stack. The oxygen supplied to fuel cell **202a** may be diluted with inert gases (inerts). By "inerts," it is meant gases that are not used by the fuel cell **202a** to produce electricity, but only dilute one or more of the reactants (oxygen and hydrogen). It should be noted that in other embodiments, fuel cell **202a** may operate on pure oxygen. The oxygen supplied to fuel cell **202a** may be supplied by air, pure oxygen or a combination of air and pure oxygen as shown in Fig. 2a. Oxygen entering fuel cell **202a** is first diluted with air in the illustrated embodiment. The air may be supplied from the ambient environment and is directed through a filter **218** and displaced by pump **220** to be combined with the oxygen. The diluted oxygen enters fuel cell **202a** through oxygen inlet **208**, where it reacts with hydrogen to generate electricity and form water as a reactant product. The water reactant product exits fuel cell **202a**, along with excess oxygen not consumed in the reaction and inerts from the air, through oxygen outlet **210**.

Oxygen recycle system **214a** recycles the oxygen and inerts exiting through oxygen outlet **210** back to oxygen inlet **208** for reuse by fuel cell **202a**. Oxygen recycle system **214a** includes reactant product recovery system **216** that separates the water reactant product from the oxygen and inerts, with the separated oxygen and inerts being

displaced by pump **217** back to oxygen inlet **208**. The water reactant product can be discharged or reused if electrical power generator **200a** is part of a closed loop/regenerative system.

Electrical power generator **200a** includes a humidifier **222** that humidifies hydrogen before the hydrogen enters fuel cell **202a**. Hydrogen enters fuel cell **202a** through hydrogen inlet **204**. Excess hydrogen not consumed during operation of fuel cell **202a** exits fuel cell **202a** through hydrogen outlet **206**. Any inerts that have diffused to the anode side from the cathode side will also exit fuel cell **202a** through hydrogen outlet **206**. Hydrogen recycle system **212** recycles hydrogen from hydrogen outlet **206** to hydrogen inlet **204** for reuse in fuel cell **202a**.

Hydrogen recycle system **212** includes a conduit **221** that extends from hydrogen outlet **206** to separator inlet **230**. An accumulator **226** (e.g., a tank, baffles or an inflatable balloon) is located along conduit **221**. Accumulator **226** is fluidly interconnectable with hydrogen outlet **206** and is operable to accumulate hydrogen and inerts that exit fuel cell **202a** through hydrogen outlet **206**. A valve **224**, also located along conduit **221**, is operable to fluidly isolate accumulator **226** from hydrogen outlet **206**, whenever desired. Hydrogen recycle system **212** also includes a separator **228** that separates hydrogen from inerts. Separator **228** has a first inlet **230** that is fluidly interconnectable with accumulator **226**. Separator **228** receives a feed of hydrogen and inerts from accumulator **226** through first separator inlet **230**. Thus, there is a flowpath as indicated by reference numeral **223** from hydrogen outlet **206** to first inlet **230** that is created by conduit **221** and accumulator **226**. The hydrogen that is separated from the inerts by separator **228** exits separator **228** through a first separator outlet **232**, which is

fluidly interconnectable with the hydrogen inlet **204**, through a conduit **233**. A flowpath indicated by reference numeral **231**, from first separator outlet **232** to hydrogen inlet **204**, is created by conduit **233**. The inerts and any remaining hydrogen that has not been separated by separator **228** exit separator **228** through a second separator outlet **234**. A conduit **235** extends from separator outlet **234** and is fluidly interconnectable with conduit **221**. The second separator outlet **234** is fluidly interconnectable with the accumulator **226** by conduit **235** (without progressing through fuel cell **202a**) or with the oxygen inlet **208**, by conduit **239** depending upon the configuration of a three-way valve **238**. The inerts and remaining hydrogen may be pumped out of separator **228** and back into accumulator **226** by pump **236** with valve **238** in one configuration. The inerts and remaining hydrogen pumped out of separator **228** will combine with hydrogen and inerts accumulating in accumulator **226** from fuel cell **202a**. Thus, there is a flowpath indicated by reference numeral **237** from separator outlet **234** to separator inlet **230**, created by conduit **235**, pump **236**, conduit **221** and accumulator **226**. In another configuration, valve **238** is operable to fluidly isolate second outlet **234** from fluid accumulator **226**, and to thereby direct a flow through conduit **239** to oxygen inlet **208** and into fuel cell **202a**. Therefore, a flowpath indicated by reference numeral **241** from separator outlet **234** to oxygen inlet **208** is created by conduit **235**, pump **236** and conduit **239**.

Hydrogen recycle system **212** can be operated in two different modes. In a first mode, valve **224** is operated to allow fluid communication between the hydrogen outlet **206** and accumulator **226**, and valve **238** is operated to allow fluid communication between second outlet **234** and accumulator **226** (without progressing through fuel cell **202a**). A hydrogen feed enters fuel cell **202a** through hydrogen inlet **204**. Some

hydrogen will be consumed by fuel cell **202a** to produce electricity. Unconsumed hydrogen will exit fuel cell **202a** through hydrogen outlet **206**, along with any inerts that have diffused to the anode side of the fuel cell. The hydrogen and inerts exiting through hydrogen outlet **206** will accumulate in accumulator **226**. Hydrogen and inerts from accumulator **226** are then directed to separator **228** through separator inlet **230**. Separator **228** will separate at least a portion of the hydrogen from the inerts, and recycle the separated portion of hydrogen back to the hydrogen inlet **204** through a first separator outlet **232**. The inerts and remaining hydrogen that was not separated out by separator **228** are pumped out of separator **228** and back to accumulator **226** (without having to pass back through fuel cell **202a**), by pump **236** (there is no fluid flow through conduit **239** to oxygen inlet **208** at this time). The hydrogen and inerts pumped out of separator **228** will combine with hydrogen and inerts being accumulated from fuel cell **202a**. The hydrogen and inerts will be continually recirculated from accumulator **226** to separator **228** and again to accumulator **226**. Because separator **228** removes hydrogen from the recirculating fluid of hydrogen and inerts, the concentration of inerts in the recirculating fluid will increase over time. The recirculation of hydrogen and inerts will typically continue until the inerts in accumulator **226** reach a predetermined concentration. Any way of determining when to change the operational mode of the hydrogen recycle system **212** may be utilized.

When the inerts in accumulator **226** reach a predetermined concentration or otherwise when a determination is made to change operational modes, the hydrogen recycle system **212** may be operated in a second mode of operation. In the second mode of operation, valve **224** is then operated so that accumulator **226** is fluidly isolated from

hydrogen outlet **206** and does not accumulate any additional hydrogen and inerts from fuel cell **202a**. The hydrogen and inerts are circulated from accumulator **226** to separator **228**, where hydrogen is separated and directed to fuel cell **202a** through hydrogen inlet **204**, with the unseparated hydrogen and inerts being pumped by pump **236** back to accumulator **226** (without first passing through fuel cell **202a**, and thereby bypassing fuel cell **202a**), as described above. However, since accumulator **226** is not accumulating additional hydrogen from fuel cell **202a**, the fluid recirculating from accumulator **226** to separator **228** and back to accumulator **226** is being depleted of hydrogen. The recirculation in this fashion may continue until a desired portion of the hydrogen has been separated from the inerts. Preferably, substantially all of the hydrogen is separated from the inerts (e.g., hydrogen remains in only parts per thousand and preferably only in parts per million). When substantially no hydrogen remains in the fluid or otherwise when a determination has been made that hydrogen recovery operations may be terminated, valve **238** is operated to create fluid isolation between pump **236** and accumulator **226** and to create fluid communication between pump **236** and oxygen inlet **208**. The inerts are then pumped out of separator **238** and accumulator **226** and directed to oxygen inlet **208**, where they may be advantageously used to dilute the oxygen entering fuel cell **202a**.

After removal of the inerts from the separator **228** and accumulator **226**, valve **238** is operated to again fluidly isolate pump **236** from oxygen inlet **208** and allow fluid communication between pump **236** and accumulator **226**.

It should be noted that fuel cell **202a** is operable to produce electricity when fuel recycle system **212** is operating in either the first mode or the second mode described

above. Alternatively, fuel cell **202a** may be stopped from producing electricity when system **212** is operating in either the first mode or the second mode described above.

As described above, the electrical power generator **200a** illustrated in Fig. 2a has the advantage of removing inerts from the hydrogen, preferably without any significant loss of the valuable hydrogen. Additionally, in the electrical power generator **200a**, the inerts are reused for diluting the oxygen before entering fuel cell **202a**. The ability to conserve reactants and recycle the inerts for reuse makes the electrical power generator **200a** particularly suitable for use in closed loop/regenerative power plants.

Fig. 2b is a schematic of a second embodiment of an electrical power generator and that is identified by reference numeral **200b**. Corresponding parts from Fig. 2a are numbered the same in Fig. 2b. Electrical power generator **200b** includes a fuel cell **202b** that operates to produce electricity by reacting hydrogen and oxygen. In this embodiment, fuel cell **202b** operates on pure oxygen. Electrical power generator **200b** further includes the hydrogen recycle system **212** previously described with respect to Fig. 2a. However, because fuel cell **202b** operates on pure oxygen, the inerts removed by recycle system **212** are not recycled to oxygen inlet **208**. Rather, as shown in Fig. 2b, the inerts may be vented out to the ambient environment or directed to any appropriate storage vessel.

Electrical power generator **200b** also has an oxygen recycle system **214b**, which recycles the oxygen not consumed in the fuel cell **202b** from oxygen outlet **210** back to oxygen inlet **208** for reuse by fuel cell **202b**. Oxygen recycle system **214b** includes reactant product recovery system **216** previously described above. Because fuel cell **202b** operates on pure oxygen, any inerts that have entered electrical power generator

200b and combined with the excess oxygen exiting oxygen outlet **210** may be removed prior to recycling unconsumed oxygen from oxygen outlet **210** to oxygen inlet **208**. Consequently, oxygen recycle system **214b** further includes a system similar to hydrogen recycle system **212**, described with respect to Fig. 2a, for separating oxygen from inerts.

Oxygen recycle system **214b** includes an accumulator **242** (e.g. a tank, baffles or an inflatable balloon). Accumulator **242** is fluidly interconnectable with oxygen outlet **210** and is operable to accumulate oxygen and inerts that exit fuel cell **202b** through oxygen outlet **210**. A valve **240** is operable to fluidly isolate accumulator **242** from oxygen outlet **210**, whenever desired. Oxygen recycle system **214b** also includes a separator **244** that separates oxygen from inerts. Separator **244** has a first inlet **246** that is fluidly interconnectable with accumulator **242**. Separator **244** receives a feed of oxygen and inerts from accumulator **242** through first separator inlet **246**. The oxygen that is separated from the inerts by separator **244** exits separator **244** through a first separator outlet **248**, which is fluidly interconnectable with the oxygen inlet **208**. The inerts and any remaining oxygen that has not been separated by separator **244** exit separator **244** through a second separator outlet **250**. The second separator outlet **250** is fluidly interconnectable with the accumulator **242** without having to pass back through the fuel cell **202b**. The inerts and remaining oxygen are pumped out of separator **244** and back into accumulator **242** by pump **252**. The inerts and remaining oxygen pumped out of separator **244** will combine with oxygen and inerts accumulating in accumulator **242** from fuel cell **202b**. A valve **254** is operable to fluidly isolate second outlet **250** from fluid accumulator **242**.

Similar to hydrogen recycle system **212**, oxygen recycle system **214b** can be operated in two different modes. In a first mode, valve **240** is operated to allow fluid communication between the oxygen outlet **210** and accumulator **242**, and valve **254** is also operated to allow fluid communication between second outlet **250** and accumulator **242** (bypassing the fuel cell **202b**). An oxygen feed enters fuel cell **202b** through oxygen inlet **208**. Some oxygen will be consumed by fuel cell **202b** to produce electricity. Unconsumed oxygen will exit fuel cell **202b** through oxygen outlet **210**, along with any inerts that may have diffused into the fuel cell **202b** and the water reactant product. The oxygen, inerts and water exiting through oxygen outlet **210** will enter reactant product recovery system **216**, where the water will be separated out from the oxygen and inerts. The oxygen and inerts exiting product recovery system **216** will accumulate in accumulator **242**. Oxygen and inerts from accumulator **242** are then directed to separator **244** through separator inlet **246**. Separator **244** will separate at least a portion of the oxygen from the inerts, and recycle the separated portion of oxygen back to the oxygen inlet **208** through a first separator outlet **248**. The inerts and remaining oxygen that was not separated out by separator **244** are pumped out of separator **244** and back to accumulator **242** by pump **252** (again, bypassing the fuel cell **202b**). The oxygen and inerts pumped out of separator **244** combine with oxygen and inerts being accumulated from reactant product recovery system **216**. The oxygen and inerts will be continually recirculated from accumulator **242** to separator **244** and again to accumulator **242**. Because separator **244** removes oxygen from the recirculating fluid of oxygen and inerts, the concentration of inerts in accumulator **242** will increase over time. The recirculation of oxygen and inerts will typically continue until the inerts in accumulator **242** reach a

predetermined concentration. Any way of determining when to change the operational mode of the oxygen recycle system **214b** may be utilized.

When the inerts in accumulator **242** reach a predetermined concentration or otherwise when a determination is made to change operational modes, the oxygen recycle system **214b** may be operated in a second mode of operation. In the second mode of operation, valve **240** is then operated so that accumulator **242** is fluidly isolated from oxygen outlet **210** and does not accumulate any additional oxygen and inerts from reactant product recovery system **216**. The oxygen and inerts are recirculated from accumulator **242** to separator **244**, where oxygen is separated and directed to fuel cell **202b**, with the unseparated oxygen and inerts being displaced by pump **252** back to accumulator **242**, as described above. However, since accumulator **242** is not accumulating additional oxygen from reactant product recovery system **216**, the fluid recirculating from accumulator **242** to separator **244** and back to accumulator **242** is continually being depleted of oxygen. The recirculation of oxygen and inerts preferably continues until substantially all of the oxygen has been separated from the inerts or otherwise when a determination has been made that oxygen recovery operations may be terminated. When substantially no oxygen remains in the fluid or otherwise when a determination has been made that oxygen recovery operations may be terminated, valve **254** is operated to create fluid isolation between pump **252** and accumulator **242** and to create fluid communication between pump **236** and the ambient environment or an appropriate storage vessel. The inerts are then displaced out of separator **244** and accumulator **242** to the ambient environment or an appropriate storage vessel by pump

252. After removal of the inerts from the separator **244** and accumulator **242**, valve **254** is operated to again allow fluid communication between pump **252** and accumulator **242**.

In electrical power generator **200b**, hydrogen recycle system **212** and oxygen recycle system **214b** may both operate in their first mode of operation when fuel cell **202b** is operated to produce electricity, and hydrogen recycle system **212** and oxygen recycle system **214b** may both operate in their second mode of operation when fuel cell **202b** is not operating to produce electricity. However, each could operate in any mode without regard to operation of the other and without regard to whether fuel cell **202b** is operating to produce electricity.

The separators (i.e. **228** and **244**) described in Fig. 2a and 2b for separating the reactants (oxygen and hydrogen) from inerts can be any suitable device that selectively separates the desired reactant from inerts. Figs. 3 and 4 illustrate examples of two possible separators that may be used by the hydrogen recycle system **212** and the oxygen recycle system **214b**, respectively.

Fig. 3 illustrates one embodiment of a separator that may be used by the hydrogen recycle system **212** and that is identified by reference numeral **300**. Separator **300** includes an anode **302**, a cathode **304** and a solid electrolyte **306**. Solid electrolyte **306** is made of a material that is capable of selectively transporting hydrogen from anode **302** to cathode **304**, such as for example a fluoropolymer used in PEM fuel cells. Additionally, separator **300** comprises an inlet **308** for intake of hydrogen and inerts, a first outlet **310** for exit of the hydrogen that is separated from the inerts, and a second outlet **312** for exit of the inerts as well as hydrogen that does not pass through the solid electrolyte **306**

toward cathode **304**. A secondary power source **314** is used to apply a potential between anode **302** and cathode **304**.

Separator **300** operates by receiving a feed of hydrogen and inerts through inlet **308**. The hydrogen and inerts contact anode **302**. The surface of anode **302** has a catalyst, similar to catalysts used in PEM fuel cells, that separates the hydrogen into protons and electrons. An electric potential (i.e. a voltage) is applied by secondary power source **314** between anode **302** and cathode **304**. The potential applied between anode **302** and cathode **304** can be as large as about 1.2 volts or as small as about 25 millivolts, but is preferably in a range from about 1.1 volts to about 40 millivolts, such as from about 1 volt to about 50 millivolts. With the applied potential, the protons are transported from the anode **302** across the solid electrolyte **306** and recombine with electrons at cathode **304** to reform hydrogen, which exits separator **300** through outlet **310**. The inerts remain on anode **302** and exit through outlet **312**. Hydrogen that does not pass through solid electrolyte **306** in the direction of cathode **304** also exits through outlet **312**.

Fig. 4 illustrates one embodiment of a separator that may be used in the oxygen recycle system **214b** and that is identified by reference numeral **400**. Separator **400** comprises an anode **402**, a cathode **404** and a solid electrolyte **406**. Solid electrolyte **406** is made of a material that is capable of selectively transporting oxygen from cathode **404** to anode **402**, such as for example metal oxides used in solid oxide fuel cells. Any appropriate metal oxide may be used as solid electrolyte **406**, for example yttria-stabilised zirconia, gadolinium doped ceria, hafnia or bismuth oxide. Additionally, separator **400** comprises an inlet **408** for intake of oxygen and inerts, a first outlet **410** for exit of the oxygen that is separated from the inerts, and a second outlet **412** for exit of the

inerts as well as any remaining oxygen that does not pass through the solid electrolyte **406** toward anode **402**. A secondary power source **414** is used to apply a potential between cathode **404** and anode **402**.

Separator **400** operates by receiving a feed of oxygen and inerts through inlet **408**. The oxygen and inerts contact cathode **404**. An electric potential (i.e. a voltage) is applied by secondary power source **414** between cathode **404** and anode **402**. The potential applied between cathode **404** and anode **402** can be as large as about 1 volt or as small as about 25 millivolts, but is preferably in a range from about 0.75 volts to about 40 millivolts, such as from about 0.5 volts to about 50 millivolts. Similar to a solid oxide fuel cell, the oxygen at cathode **404** is reduced to negatively charged oxygen ions. With the applied potential, the oxygen ions are transported from cathode **404** across solid electrolyte **406** and combine at anode **402** to reform oxygen, which exits separator **400** through outlet **410**. The inerts remain on cathode side **404** and exit through outlet **412**. Oxygen that does not pass through the solid electrolyte **406** in the direction of anode **402** also exits through outlet **412**.

It should be noted, that recycle systems **212** and **214b** may utilize a single separator **300** or **400**, or may utilize a plurality of separators **300** and **400**. Separators **300** and **400** are merely illustrative examples of possible separators that may be used by the hydrogen recycle system **212** and the oxygen recycle system **214b**. As stated above, any suitable device that selectively separates the desired reactant from inerts may be used.

Referring now to Fig. 5, Fig. 5 shows a schematic of another embodiment of an electrical power generator that is identified by reference numeral **500**. Electrical power generator **500** is similar to electrical power generator **200a** in Fig. 2a. Corresponding

parts from Fig. 2a are numbered the same in Fig. 5. Electrical power generator **500** includes fuel cell **202a** that operates to produce electricity by reacting hydrogen and oxygen. Fuel cell **202a** operates as described above. Electrical power generator **500** also includes hydrogen recycle system **212** that is operable as described above with respect to Fig. 2a. Hydrogen recycle system **212** separates hydrogen from inerts, recycles the separated hydrogen to hydrogen inlet **204** and directs the inerts to oxygen inlet **208** to dilute the oxygen provided to fuel cell **202a** for production of electricity.

Electrical power generator **500** further includes oxygen recycle system **214c**, which recycles oxygen and inerts from oxygen outlet **210** back to oxygen inlet **208** for reuse by fuel cell **202a**. Oxygen recycle system **214c** operates similarly to previously described oxygen recycle system **214a**. Oxygen recycle system **214c** includes reactant product recovery system **216c** that separates the water reactant product from the oxygen and the inerts. The separated oxygen and inerts are displaced by pump **217** back to oxygen inlet **208**.

In this embodiment, reactant product recovery system **216c** includes a primary recovery chamber **502**. Primary recovery chamber **502** has a primary inlet **504** for oxygen, inerts and water reactant product that exit fuel cell **202a**. Primary recovery chamber **502** separates the oxygen and inerts from the water reactant product. The oxygen and inerts exit primary recovery chamber **502** through primary gas outlet **506** and are pumped back to oxygen inlet **208** by pump **217**. The water reactant product exits primary recovery chamber **502** through primary liquid outlet **508**. Reactant recovery system **216c** also includes second recovery chamber **512**. Second product recovery chamber **512** includes a secondary inlet **514** that is fluidly interconnectable with primary

liquid outlet **508**. A valve **510** is operable to control the fluid communication between primary liquid outlet **508** and secondary inlet **514**. Secondary recovery chamber **512** will separate any remaining oxygen and inerts from the water reactant product. The oxygen and inerts exit secondary recovery chamber **512** through secondary gas outlet **516** and are displaced by pump **518** to be combined with oxygen, inerts and water reactant product exiting fuel cell **202a** and entering primary recovery chamber **502**, or alternatively the oxygen and inerts exiting secondary recovery chamber **512** can be directly displaced to oxygen inlet **208**. The water reactant product exits secondary recovery chamber **512** through secondary liquid outlet **520**. The water reactant product is discharged for disposal, or recycled if electrical power generator **500** is part of a closed loop/regenerative system.

Reactant product recovery system **216c** is operable to recover as much oxygen and inerts as possible from the mixture of oxygen, inerts and water reactant product exiting fuel cell **202a**. Primary recovery chamber **502** will typically recover a majority of the oxygen and inerts from the water reactant product. However, the pressure inside primary recovery chamber **502** is high enough that some oxygen and inerts will remain dissolved in the water reactant product. Consequently, if the water reactant product is discharged from primary recovery chamber **502**, electrical power generator **500** will lose valuable oxygen reactant. Secondary recovery chamber **512** allows the additional oxygen and inerts to be recovered before the water reactant product is discharged. Preferably, secondary recovery chamber **512** will be at a lower pressure than primary recovery chamber **502**, so that when the water reactant product enters secondary recovery chamber **512**, the drop in pressure will reduce the solubility of the oxygen and inerts in the water

reactant product. The reduction in solubility will cause additional oxygen and inerts to separate from the water reactant product and be recovered.

The combination of primary recovery chamber **502** and secondary recovery chamber **512** provide the advantage of recovering more oxygen and inerts from the water reactant product before the water reactant product is discharged. In a closed loop/regenerative power plant, the conservation of reactants is of paramount importance, and the embodiment illustrated in Fig. 5, which combines hydrogen recycle system **212** and reactant product recovery system **216c**, is ideally suited for use in a closed loop/regenerative system.

Fig. 6 shows a flow diagram of a closed loop/regenerative electrical power plant **600**. The electrical power plant **600** includes electrical power generator **500** from Fig. 5, reactant product storage **604**, reactant regenerator **606**, reactant storage **608** and secondary electrical power source **610**. The electrical power plant **600** is operable in at least two different modes, an electrical power generation mode and a reactant regeneration mode. The electrical power plant **600** may be operated in both of these modes simultaneously, but preferably the electrical power plant **600** is operated in only one of these modes at any given time.

When the electrical power plant **600** is operated in the electrical power generation mode, electrical power generator **500** is operated to generate electricity from oxygen and hydrogen supplied from reactant storage **608**. Water reactant product produced by electrical power generator **500** is recovered and stored in reactant product storage **604**. During the electrical power generation mode, oxygen and hydrogen are consumed in electrical power generator **500**, producing the water reactant product.

When the electrical power plant **600** is operated in the reactant regeneration mode, the reactant regenerator **606** is operated to produce the oxygen and hydrogen from the water reactant product supplied from reactant product storage **604.** Oxygen and hydrogen produced by reactant regenerator **606** are then recovered and stored in reactant storage **608**. Power to operate the reactant regenerator **606** during the regeneration mode is supplied from secondary electrical power source **610**. The secondary electrical power source **610** may include any device capable of generating electrical power, for example a photovoltaic electrical power generator, such as one or more arrays of solar cells (also referred to as photovoltaic cells) or a wind electrical power generator. Secondary power source **610** may also be used to power other devices in electrical power plant **600,** such as for example separator **228** in electrical power generator **500**. During the regeneration mode, water reactant product is consumed in reactant regenerator **606**, producing the oxygen and hydrogen to replenish reactant storage **608**, ready for the next cycle of operation in the electrical power generation mode.

Fig. 7 is a more detailed schematic of a specific embodiment of the closed loop/regenerative electrical power plant **600** of Fig. 6. Electrical power plant **600** includes the fuel cell electrical power generator **500** of Fig. 5. The electrical power generator **500** operates as previously described above. Corresponding parts from Figs. 5 and 6 are marked with the same part numbers on Fig.7.

Electrical power plant **600** has electrical power generator **500** from Fig. 5, reactant product storage **604**, reactant regenerator **606** and reactant storage **608**. Reactant product storage **604** includes water storage tanks **702** for storing the water reactant product produced by electrical power generator **500**. When power plant **600** is operated

in the electrical power generation mode, water from water storage tanks **702** is directed to a deionizer **704**, which removes ions from the water before the water is used by reactant regenerator **606** to make oxygen and hydrogen. A pump **706** directs water from deionizer **704** to reactant regenerator **606**.

Reactant regenerator **606** includes electrolyzers **712** and **714** that regenerate oxygen and hydrogen from the water supplied by reactant storage **604**. The amount of water entering electrolyzers **712** and **714** is controlled by flow limiters **708** and **710** respectively. The oxygen produced by electrolyzers **712** and **714** is directed to a water separator **716**, for separation of any water from the oxygen. The water separated in water separator **716** is displaced by pump **718** to heat exchanger **720** to remove heat from the water. A deionizer **722** removes ions from the water before the water is directed back to electrolyzers **712** and **714** to produce additional oxygen and hydrogen. The oxygen in separator **716** is directed to heat exchanger **724** to remove heat from the oxygen. The oxygen is then directed to another water separator **726** to remove any remaining water from the oxygen. The water removed from the oxygen in water separator **726** is displaced by pump **728** and is combined with water exiting water separator **716**. The water is recycled to electrolyzers **712** and **714** as described above. The oxygen from water separator **726** is then directed to reactant storage **608**, where it is stored in oxygen storage tanks **730**.

The hydrogen produced by electrolyzers **712** and **714** is directed to a water separator **732** to separate water that may have exited electrolyzers **712** and **714** with the hydrogen. Water separated in water separator **732** is displaced by pump **734** into water separator **716**, where it combines with the water in water separator **716** and is recycled to

the electrolyzers **712** and **714**. The hydrogen from water separator **732** is directed to heat exchanger **736** where heat is removed from the hydrogen. The hydrogen then enters another water separator **738** to remove additional water that may be associated with the hydrogen. The water removed in separator **738** is combined with the water removed from water separator **732** and is recycled to the electrolyzers **712** and **714**. The hydrogen from water separator **738** is then directed to reactant storage **608**, where it is stored in hydrogen storage tanks **740**.

Oxygen and hydrogen stored in reactant storage **608** are utilized by electrical power generator **500** to produce electricity. Valve **750** is operable to control fluid communication between hydrogen storage tanks **740** and hydrogen inlet **204**. Valve **742** is operable to control fluid communication between oxygen storage tanks **730** and oxygen inlet **208**. When electrical power plant **600** is operating in electrical power generation mode, oxygen is directed from oxygen storage tanks **730** to heat exchanger **746**, which cools the oxygen before it enters into fuel cell **202a**. The oxygen is diluted with air or inerts recycled from hydrogen recycle system **212** before entering fuel cell **202a**. The air is supplied by the ambient environment and enters electrical power plant **600** through air inlet **748**. In other embodiments, the air could be supplied from air storage tanks or as stated previously, fuel cell **202a** could be operated on pure oxygen. The diluted oxygen enters fuel cell **202a** through oxygen inlet **208**. The oxygen reacts with the hydrogen in fuel cell **202a** to generate electricity and form the water reactant product. The oxygen not consumed during the reaction to produce electricity exits through oxygen outlet **210** and is recycled by oxygen recycle system **214c** as previously described with respect to Fig. 5. The water reactant product, substantially free of oxygen and inerts, exits secondary

recovery chamber **512** through secondary liquid outlet **520** and is directed to reactant storage **604**, where it is stored in water storage tanks **702**.

When electrical power plant **600** is operating in electrical power generation mode, hydrogen is directed from hydrogen storage tanks **740** to heat exchanger **752**, which cools the hydrogen before it enters into fuel cell **202a**. The hydrogen is then directed to humidifier **222**, which humidifies the hydrogen before it enters fuel cell **202a**. The humidified hydrogen enters fuel cell **202a** through hydrogen inlet **204**. The hydrogen reacts with the oxygen in fuel cell **202a** to generate electricity and form the water reactant product. The hydrogen not consumed during the reaction to produce electricity exits through hydrogen outlet **206** and is recycled by hydrogen recycle system **212**, which operates as previously described with respect to Fig. 2a.

As previously stated with respect to Fig. 6, electrical power plant **600** may be operated in electrical power generation mode and reactant regeneration mode simultaneously, but preferably the electrical power plant is operated in only one of these modes at any given time.

Additionally, electrical power plant **600** includes heat exchanger **756** and pump **754**. Pump **754** transfers a heat transfer fluid through fuel cell **202a** and heat exchangers **746**, **752** and **756**. The heat transfer fluid is circulated through the heat exchangers (**746**, **752** and **756**) and is used to cool fuel cell **202a** and the reactants (oxygen and hydrogen) before the reactants enter fuel cell **202a**.

Electrical power plant **600** also includes a heat management system **700** that is thermally interconnectable to heat exchangers **756**, **724**, **736** and **720**. Valves **778**, **774**, **776** and **772** control the flow of a heat transfer fluid through heat exchangers **756**, **724**,

736 and **720** and consequently control the thermal communication of the heat exchangers (**756**, **724**, **736** and **720**) with heat management system **700**. The heat management system **700** includes a reservoir **768** for storing the heat transfer fluid, pumps **770**, pump **760**, valve **762**, heat exchanger **764** and heat exchanger **766**. Pumps **770** are operable to transfer the heat transfer fluid in reservoir **768** to heat exchangers **756**, **724**, **736** and **720**. After the heat transfer fluid has circulated through heat exchangers **756**, **724**, **736** and **720**, it circulates through heat exchangers **764** and/or **766**, where any heat previously transferred to the heat transfer liquid from heat exchangers **756**, **724**, **736** and **720** is dissipated to the environment. Pump **760** is operable to create a flow of heat transfer fluid into heat exchanger **764**. Valve **762** is operable to control whether the heat transfer fluid progresses through heat exchanger **764** before passing through heat exchanger **766**, or whether a portion of the heat transfer fluid passes directly to heat exchanger **766**. After heat is dissipated to the environment via heat exchangers **764** and **766**, the heat transfer fluid is directed back to reservoir **768** for storage and eventual circulation back to heat exchangers **756**, **724**, **736** and **720**.

The electrical power plant **600** may be used in any application that utilizes electrical power. For example, power plant **600** may be a part of a mobile vehicle such as an automobile, a sea vessel or an airship. Electrical power plant **600** could provide the necessary power for the vehicle's propulsion system, an electric motor, the vehicle's communication system or all of the foregoing. In other applications, electrical power plant **600** could provide electrical power for use in stationary terrestrial applications such as to power homes, office buildings or stationary communication systems. The electrical power plant **600** could be used to provide power to any electrical load.

The foregoing discussion of the invention has been presented for purposes of illustration and description. The foregoing is not intended to limit the invention to only the form or forms specifically disclosed herein. Consequently, variations and modifications commensurate with the above teachings, and the skill or knowledge of the relevant art, are within the scope of the present invention. The embodiments described hereinabove are further intended to explain best modes known for practicing the invention and to enable others skilled in the art to utilize the invention in such, or other, embodiments and with various modifications required by the particular applications or uses of the present invention. It is intended that the appended claims be construed to include alternative embodiments to the extent permitted by the prior art. Although the description of the invention has included description of one or more possible implementations and certain variations and modifications, other variations and modifications are within the scope of the invention, *e.g.*, as may be within the skill and knowledge of those in the art after understanding the present disclosure. It is intended to obtain rights which include alternative embodiments to the extent permitted, including alternate, interchangeable and/or equivalent structures, functions, ranges or steps to those claimed, whether or not such alternate, interchangeable and/or equivalent structures, functions, ranges or steps are disclosed herein, and without intending to publicly dedicate any patentable subject matter. Moreover, any of the features of any embodiment may be combined in any compatible manner with any feature(s) of any other embodiment. For example, any of the features described with respect to any of the embodiments for the electrical power generator described with respect to any of Figures 2a, 2b, and 5 may be incorporated into any closed loop/regenerative electrical power plant described with

respect to Figs. 6-7. Also, any feature or operation of any portion of the electrical power plant described with respect to any of Figures 2a, 2b and 5-7 may be incorporated in any combination into the method of the invention for generating electrical power.

Additionally, flowpaths, created by the features/components illustrated in the figures, are not limited to those features/components that are illustrated in the figures. In other embodiments, the flowpaths may be created using conduits or other features/components not shown in the figures.

The terms "comprise", "include", "have" and "contain", and variations of those terms, as may be used in relation to the presence of a feature, are intended to indicate only that a particular feature is present, and are not intended to limit the presence of other features.